WATER QUALITY

Ambient Water Quality Guidelines for Chloride

Overview Report

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Environment Management Act, 1981

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Ambient water quality guidelines for chloride

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Summary

This document is one in a series that establishes ambient water quality guidelines for British Columbia (Table 1). This document is mainly based on a report prepared by the BC Ministry of Water, Land and Air Protection, BC Ministry of Transportation and Highways, BC Buildings Corporation and the Canadian Association of Petroleum Producers (Bright and Addison 2002), and a background report prepared for the Canadian Priority Substance List 2 Assessment of the toxicity of the application of road salt to the aquatic environment (Evans and Frick 2001). The guidelines for chloride set forth in this document are intended to protect drinking water, recreation and aesthetics, freshwater and marine aquatic life, agricultural water (irrigation and livestock watering) and wildlife uses. These guidelines are briefly described in the Section on Recommended Guidelines and are discussed in greater detail in the Appendix to the report.

· Top

Table 1. Recommended guidelines for chloride

Water Use	Guideline (mg Chloride/L)
Drinking water	250
Recreation and Aesthetics	None
Freshwater Aquatic Life * **Maximum Concentration** + **30-d Average Concentration** ++	 600 150
Marine Life	Human activities should not cause the chloride of marine and estuarine waters to fluctuate by more than 10% of the natural chloride expected at that time and depth.
Irrigation	100
Livestock Watering	600
Wildlife	600

* When ambient chloride concentration in the environment exceeds the guideline, then further degradation of the ambient or existing water quality should be avoided
+ Instantaneous maximums
++ Average of five weekly measurements taken over a 30-day period

The application of road salt for winter accident prevention is an important source of chloride to the environment, which is increasing over time due to the expansion of road networks and increased vehicle traffic. Road salt (most often sodium chloride) readily dissolves and enters aquatic environments in ionic forms. Although chloride can originate from natural sources, most of the chloride that enters the environment is associated with the storage and application of road salt. As such, chloride-containing compounds commonly enter surface water, soil, and ground water during snowmelt.

Chloride ions are conservative, which means that they are not degraded in the environment and tend to remain in solution, once dissolved. Chloride ions that enter ground water can ultimately be expected to reach surface water and, therefore, influence aquatic environments and humans. Among the species tested, freshwater aquatic plants and freshwater invertebrates tend to be the most sensitive to chloride. Recently, the Canadian government classified road salt as toxic under the *Canadian Environmental Protection Act* (1999).

· Top

Preface

The Ministry of Water, Land and Air Protection develops ambient water quality guidelines for British Columbia. This work has two goals:

- to provide guidance for the evaluation of data on water, sediment, and biota; and,
- to provide basis for setting site-specific ambient water quality objectives.

The guidelines represent safe conditions or safe levels of a substance in water. A water quality

guideline is defined as "a maximum and/or a minimum value for a physical, chemical or biological characteristic of water, sediment or biota, which should not be exceeded to prevent detrimental effects from occurring to a water use under given environmental conditions."

The guidelines are applied province-wide, but they are use-specific, and are being developed for these water uses:

- raw drinking water, public water supply and food processing[1];
- aquatic life and wildlife;
- agriculture (livestock watering and irrigation);
- recreation and aesthetics[2]; and
- industrial water supplies.

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[1] The guidelines apply to an ambient raw water source before it is diverted or treated for domestic use. The Ministry of Health Services regulates the quality of water for domestic use after it is treated and delivered by a water purveyor.

[2] Guidelines relating to public health at bathing beaches will be the same as those developed by the Ministry of Health, which regulates the recreation and aesthetic water use.

The guidelines are established after considering the scientific literature, existing guidelines from other jurisdictions, and environmental conditions in British Columbia. The scientific literature provides information about the effects of toxicants on various life forms. This information is not always conclusive because it is usually based on laboratory work that, at best, only approximates field conditions. To compensate for this uncertainty and to facilitate application of the "precautionary principle", the guidelines have built-in safety factors that are conservative, but consider natural background conditions in the province.

The guidelines are used to set ambient site-specific water quality objectives for specific waterbodies. In setting the objectives, consideration is also given to present and future water uses, waste discharges, hydrology, limnology, oceanography, and existing background water quality.

In most cases, the objectives are the same as the guidelines. However, when natural background levels exceed the guidelines, the site-specific objectives could be less stringent than the guidelines. In rare instances — for example, if the resource is unusually valuable or of special provincial significance — the safety factor could be increased to support the establishment of objectives that are more stringent than the guidelines. Another approach would be to develop site-specific objectives by conducting toxicity experiments in the field or applying other procedures (MacDonald 1997).

Neither the guidelines nor the objectives derived from them have any legal standing in British Columbia. However, the objectives can be used to calculate waste discharge limits for contaminants. These limits are outlined in waste management permits, orders, and approvals, all of which have legal standing. Objectives are not usually incorporated as conditions of a permit.

Water quality guidelines are subject to review and revision as new information becomes available or as other circumstances dictate.

Top

Introduction

Chloride compounds include those containing a chlorine atom as a negatively charged anion (Cl-), such as sodium chloride (NaCl). Chlorine[3] is a halogen (salt-forming) element with a boiling point of -33.9°C. Chlorine is never found in free form in nature, and occurs most commonly as sodium chloride. Chloride compounds are highly soluble in water[4], in which they persist in dissociated form as chloride anions with their corresponding positively charged cations (e.g., sodium).

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[3] The atomic weight of chlorine is 35.45, and its CAS number is 7782-50-5.

[4] The solubility of sodium chloride is 35.7g/100g water at 0°C.

Chloride is widely distributed in nature, generally in the form of sodium (NaCl) and potassium (KCl) salts; it constitutes about 0.05% of the earth's outer crust. By far the greatest amount of chloride found in the environment is in the oceans. Salt deposits occur frequently underground where they are mined for various industrial and domestic purposes. The Canadian salt industry produces 12.5 million metric tonnes annually from major rock salt mines in Ontario, Quebec, and New Brunswick and from vacuum pan refineries in Alberta, Saskatchewan, Ontario, New Brunswick, and Nova Scotia; nearly three-quarters of this total is rock salt used primarily for highway de-icing.

The application of road salt for winter accident prevention represents the single largest use of salt in British Columbia and serves as the primary anthropogenic source of chloride to the environment. Sodium chloride is also widely used in the production of industrial chemicals such as caustic soda (sodium hydroxide), chlorine, soda ash (sodium carbonate), sodium chlorite, sodium bicarbonate, and sodium hypochlorite. Potassium chloride is used in the production of fertilizers. In addition to the salting of highways to control ice and snow, other sources of chloride to the environment include dissolution of salt deposits, effluents from chemical industries, oil well operations, sewage, irrigation drainage, refuse leachates, sea spray, and seawater intrusion in coastal areas.

In freshwater, natural background concentrations of chloride are on the order of 1 to 100 mg/L, with maximum observed surficial concentrations in B.C. in the range of 13 to 140 mg/L (Bright and Addison 2002). High concentrations of chloride, related to the use of road salt on roads or released from storage yards or snow dumps, have been measured in ground water adjacent to storage yards, in small ponds and water courses draining large urbanized areas, and in streams, wetlands and lakes draining major roadways. While the highest concentrations of chloride are usually associated with winter and spring thaws, elevated chloride concentrations have also been measured during summer low flow periods.

As part of the CEPA Priority Substances List Assessment, Evans and Frick (2001) compiled information of the level of chlorides in the Canadian environment. The results of that review indicated that chloride concentrations in roadside snow ranged from <100 mg/L to 10,000 mg/L, with concentrations typically in the 4,000 mg/L range. By comparison, snow melt from snow storage dumps had chloride concentration ranges of 300 to 1,200 mg/L. The highest chloride concentrations are typically found in roadside ditches where melt-water is concentrated (highest reported value in Evans and Frick (2001; Table 4-5) was 19,135 mg/L for highway runoff in Ontario). The next highest concentrations (up to 4,310 mg/L) were observed in rivers and creeks in highly populated areas with significant use of road salt. Small lakes and ponds were more strongly affected by road salt than larger lakes, but are not as strongly influenced as creeks or rivers. For most of the small lakes that were sampled, chloride concentrations were below 200 mg/L (Evans and Frick 2001).

Chloride is an essential element for aquatic and terrestrial biota, representing the main extracellular anion in animals, including humans. It is a highly mobile ion that easily crosses cell membranes and is involved in maintaining proper osmotic pressure, water balance, and acid-base balance in animal tissues. Recent studies indicate that the chloride ion also plays an active role in renal function, neurophysiology, and nutrition.

Food represents the principal source of chloride that is consumed by humans. Approximately 0.6 g of chloride per day is ingested in a salt-free diet. Due to the addition of salt to food, the daily intake of chloride averages 6 g and may range as high as 12 g. If one assumes that daily water consumption is 1.5 L and that the average concentration of chloride in drinking water is 10 mg/L, the average daily intake of chloride from drinking water is approximately 15 mg per person, or only about 0.25% of the average intake from food.

Although chloride is an essential element for maintaining normal physiological functions in all aquatic organisms, elevated or fluctuating concentrations of this substance can be detrimental. More specifically, exposure to elevated levels of chloride in water can disrupt osmoregulation in aquatic organisms leading to impaired survival, growth, and/or reproduction. Because excess chloride is most frequently actively excreted from animal tissues via the kidneys or equivalent renal organs to achieve osmoregulatory balance, the bioaccumulation potential of chloride is low. Several factors such as dissolved oxygen concentration, temperature, exposure time and the presence of other contaminants influence chloride toxicity. However, few studies have systematically evaluated the influence of confounding variables on chloride toxicity in aquatic environments.

· Top

Recommended Guidelines

1. Drinking Water

It is recommended that the total concentration of chloride in drinking water should not exceed 250 mg/L.

Rationale: This guideline was recommended by the Canadian Council of Ministers of the Environment to protect the aesthetic qualities of drinking water (CCME 1999). More specifically, the CCME water quality guideline was established because chloride imparts an undesirable taste to water and to beverages prepared from water. In addition, it can cause corrosion in water distribution systems. The taste threshold for chloride varies depending on the associated cation that is present (e.g., sodium, potassium, etc.) and is generally in the range of 200 to 300 mg/L (Health Canada 1996). Chloride concentrations detected by taste in drinking water by panels of 18 or more people were 210, 310 and 222 mg/L for the sodium, potassium and calcium salts, respectively. The taste of coffee was affected when brewed with water containing chloride concentrations of 400, 450, and 530 mg/L from sodium chloride, potassium chloride, and calcium chloride, respectively.

2. Recreation and Aesthetics

It is unlikely that chloride concentrations found in ambient waters would impair recreational activities, such as, wading or swimming. Therefore, no guideline is recommended for this water use.

· Top

3. Aquatic Life

Presently, there is no Canadian water quality guideline for chloride for protection of freshwater organisms. Evans and Frick (2001) evaluated the toxicity of chloride to freshwater organisms by stratifying the existing data according to the duration of chloride exposure. For the purposes of guideline derivation below, acute toxicity tests are defined as those in which duration of exposure was less than seven days; toxicity tests of seven or more days in duration are considered to

represent chronic exposures.

For exposures of 96 hours, there were 13 studies with fish, seven with cladocerans, and eight with other invertebrates (Appendix 1, Table 1). In general, fish were less sensitive to the effects of chloride than invertebrates. The 96-h LC50s ranged from 1204 to 13,085 mg chloride/L, with a geometric mean of 3940 mg chloride/L.

For chronic exposures, effective (EC50) and lethal (LC50) concentrations of chloride for nine different taxa ranged from 735 mg/L for the cladoceran, *Ceriodaphnia dubia*, to 4681 mg/L for the Eurasian watermilfoil, *Myriophyllum spicatum* (Appendix 1, Table 2).

· Top

3.1 Freshwater Aquatic Life

Freshwater: Chronic

To protect freshwater aquatic life from chronic effects, the average[5] concentration of chloride (mg/L as NaCl) should not exceed 150 mg/L.

[5] Arithmetic mean is computed from five weekly samples collected over a 30-day period.

Rationale: The recommended water quality guideline was derived by dividing the lowest LOEC (lowest observed effect concentration) from a chronic toxicity test by a safety factor of 5. The lowest LOEC for a chronic toxicity test is 735 mg/L for Ceriodaphnia dubia (Appendix 1, Table 2); this chloride concentration resulted in a 50% reduction in reproduction over the 7 day test duration. Utilizing this value and following application of a safety factor of five, the chronic guideline is 150 mg/L (rounded to nearest tenth place).

The safety factor of 5 in the derivation of the chronic guideline was justified as follows: (a) Chronic data (Appendix 1, Table 2) available from the literature were scant; (b) in a recent study, Diamond et al. (1992) found a LOEC/NOEC ratio for reproduction of 3.75 in C. dubia exposed to NaCl for 7 days. Also, LC_{50}/LC_0 of 3 and LC_{100}/LC_0 of 4 were obtained by Hughes (1973), whereas the DeGreave et al. (1991) data yielded LC_{50}/NOEC ratios that ranged from about 1.0 to 6.9; (c) additional protection may be required for those species that are more sensitive but have not yet been tested in the literature.

Freshwater: Acute

To protect freshwater aquatic life from acute and lethal effects, the maximum concentration of chloride (mg/L as NaCl) at any time should not exceed 600 mg/L.

Rationale: The guideline for maximum chloride concentration was derived by applying a safety factor of two to the 96-h EC_{50} of 1204 mg/L for the tubificid worm, Tubifex tubifex (Appendix 1, Table 1), and rounding the number to nearest tenth. Safety factors of two is applied to the acute data because of the relative strength of the acute (Appendix 1, Table 1) data set.

· Top

3.2 Marine Aquatic Life

To protect aquatic life in marine environments, human activities should not cause the chloride concentration to fluctuate by more than 10% of the natural background expected at that time and depth.

Rationale: This guideline is an interim guideline that reflects the close relationship between chloride concentration and salinity in marine environments (changes in marine salinity are reflected by equivalent changes in chloride concentration[6]). Full strength seawater in the Pacific Ocean (Pacific deep water) has salinity about 34 parts per thousand, which is equivalent to a chloride concentration of 18,980 mg/L. Euryhaline organisms can withstand salinity fluctuations, either by tolerating changes in internal osmotic pressure or by maintaining a constant osmotic pressure through osmoregulation.

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[6] Published graphs which show the relationship between total salinity and the concentration of different salt compounds can be found in U.S. Dept. of Agriculture (1954).

To protect marine aquatic life in marine environments, human activities should not cause the salinity (expressed as parts per thousand) of marine and estuarine waters to fluctuate by more than 10% of the natural salinity expected at that time and depth. This is consistent with the CCME (1999) interim salinity guideline designed to protect marine and estuarine organisms by avoiding or limiting human-induced fluctuations in the salinity regime. It is also assumed that this guideline will protect natural circulation and mixing patterns of coastal water bodies and thereby limit effects on the physiology and distribution of marine and estuarine organisms associated with such patterns.

· Top

4. Irrigation

The quality guideline for irrigation purposes is 100 mg chloride/L.

Rationale: The CCME (1999) water quality guidelines indicate that sensitive plants should not be irrigated with waters containing > 100 mg chloride/L. In contrast, the CCME (1999) indicates that chloride-tolerant plants can be irrigated with water up to 700 mg chloride/L. The lower of these two values, 100 mg chloride/L, is adopted as the water quality guideline for chloride in irrigation water in British Columbia. Waters with chloride concentrations below the guideline can be used for irrigation on all crops within the province.

5. Livestock Watering

The water quality guideline for livestock watering is 600 mg chloride/L.

Rationale: Based on the CCME (1999) water quality guidelines, the concentration of total soluble salts in water used for livestock watering should not exceed 1000 mg/L. Assuming that chloride represents 60% by weight of total soluble salts (e.g., for NaCl), then an equivalent chloride guideline is 600 mg chloride/L. Water with total soluble salt content of less than 1000 mg/L is considered excellent for all classes of livestock. Livestock health may become impaired at total soluble salt concentrations of 1000 to 3000 mg/L.

· Top

6. Wildlife

The chloride concentration in waters that are utilized by wildlife should not exceed 600 mg/L.

Rationale: Although numerical WQGs for the protection of wildlife were not located in the scientific literature, there is no reason to believe that wildlife species would be more sensitive to the effects of chloride than livestock species. For this reason, the WQG for livestock watering was adopted directly as the WQG for the protection of wildlife in British Columbia.

Application of Guidelines for Aquatic Life

Chloride is ubiquitous in the environment. Its impact on the environment depends upon environmental conditions, including dissolved oxygen concentration, temperature, exposure time, and the presence of other contaminants. These factors should be considered when the water quality guidelines are applied to assess environmental impacts of chloride.

1. Assessment of Existing Water Quality

The environmental chemistry of chloride is relatively straightforward. Following the deposition of road salt, these compounds dissociate in the environment into chloride anion and a corresponding cation (usually sodium, since sodium chloride is the predominant form of road salt). Chloride ions enter surface water, soil, and ground water after snowmelt events and remain in solution in freshwater systems.

It is important to carefully consider background levels of chloride in the local aquatic environment and to take these data into consideration when applying the WQGs. For example, in Stuart Lake situated in the upper part of the Fraser River watershed, chloride levels should be very low. Therefore, measured levels of chloride at, or above the WQGs, would likely indicate that anthropogenic sources are contributing to chloride levels and putting ecological receptors at risk. However, background levels of chloride in the lower (tidal) portions of the Fraser River are likely to be highly variable, and influenced by tidal cycles and salt wedge penetration. In this situation, elevated levels of chloride would not necessarily indicate a water quality problem.

· Top

2. Setting of Water Quality Objectives

In most cases, water quality objectives for chloride will be the same as the guidelines. When concentrations of chloride in undeveloped waterbodies are less than the recommended guidelines, then more stringent values, if justified, could apply. In some cases, socio-economic or other factors (e.g., higher background levels) may justify objectives which are less stringent than the guidelines. To adjust the guidelines recommended here to take local conditions into consideration, the BC Ministry of Environment, Lands and Parks publication, "Methods for Deriving Site-Specific Water Quality Objectives in British Columbia and Yukon" should be followed (MacDonald 1997).

Although sodium chloride is the predominant form of road salt in British Columbia, other cations in addition to sodium (e.g., calcium, magnesium and potassium) can either reduce or enhance the toxicity of chloride in natural water bodies. Complex interactions among sodium, potassium, magnesium and chloride ions may play a role in affecting the sensitivity of aquatic species to road salt runoff. Increased salt concentrations can potentially enhance the mobility of trace metals in aquatic ecosystems. Road salts can thus increase the toxicity and adverse environmental impacts of road runoff. Nutrients and organic contaminants may also be carried with road runoff, thereby contributing to stresses on aquatic organisms.

· Top

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· Top

Appendix 1: Supporting Documentation for the Recommended Water Quality Guidelines

1. Introduction

Road salts are applied to roadways in B.C. in order to prevent traffic accidents. During wintertime, traffic accidents can be reduced by 20 to 90% when icy and snowy roads are salted and reduced to bare pavement. The use of de-icing agents serves to keep Canadian roadways open and safe during the winter and to minimize traffic accidents, injuries, and mortality under icy and snowy conditions.

Sodium chloride is the most commonly applied road salt in North America. Road salt can be made up of different mixtures of compounds including calcium chloride, magnesium chloride, and potassium chloride. In the environment, salts dissociate into the chloride anion and a corresponding cation. Environment Canada estimated that during the 1997-98 winter, approximately 4,750,000 tonnes of sodium chloride and 110,000 tonnes of calcium chloride de-icers were applied to Canadian roads, resulting in an estimated 2,950,000 tonnes of chloride released to the environment. Of this amount, approximately 94,000 tonnes or road salt were applied in BC, with loading rates between 1 to 3 kg/m2 of salted road.

Ultimately, all road salts enter the environment as a result of:

1. Storage at patrol yards (including losses from storage piles and during handling);
2. Roadway application (at the time of application as well as subsequent movement of the salts off the roadways); and,
3. Disposal of waste snow.

Releases are therefore associated with both point sources (storage and snow disposal areas) and linear sources (roadway application).

· Top

2. Background

The *Canadian Environmental Protection Act* (CEPA) requires that the Ministers of Environment and Health identify substances that may be harmful to the environment or constitute a danger to human health. A substance is considered to be "CEPA toxic" if it is entering the environment in a quantity or concentration or under conditions that:

1. Have or may have an immediate or long-term harmful effect on the environment or its biological diversity;
2. Constitute or may constitute a danger to the environment on which life depends; or,
3. Constitute or may constitute a danger in Canada to human life or health.

A notice to the effect that road salt is considered to be a toxic substance in Canada was filed in the Canada Gazette on Dec. 1, 2001. The notice states that based on the available data, it is considered that road salts that contain inorganic chloride salts are entering the environment in a quantity or concentration or under conditions that have or may have an immediate or long-term harmful effect on the environment or its biological diversity or that constitute a danger to the environment on which life depends. Therefore, it is concluded that road salts that contain inorganic chloride salts with or without ferrocyanide salts are "toxic" as defined in section 64 of the *Canadian Environmental Protection Act*, 1999.

· Top

3. Effects of Chloride on Aquatic Organisms

Road salt has the potential to adversely affect a wide range of aquatic organisms. Evans and Frick (2001) reviewed the literature on the biological effects of chloride and drew a number of conclusions regarding chloride salt toxicity and effects on aquatic biota. First, tolerance to elevated

chloride concentrations decreases with increasing exposure time. Short-term exposures to concentrations of chloride in the hypersaline range (>50,000 mg/L salinity) may kill adult fish and other organisms rapidly (e.g., 15 minutes). As exposure time increases, tolerance to chloride decreases. Tolerance to chloride can be increased through the gradual increases in chloride concentrations, allowing the organism to develop mechanisms for dealing with the osmotic shock and other physiological stresses.

A number of studies reviewed by Evans and Frick (2001) measured the effects of physical variables on salinity tolerance. Aquatic biota are more tolerant of chloride in water in which oxygen concentrations are close to saturation. While some studies suggest that organisms are more tolerant to chloride at lower temperatures, other studies have shown that the reverse is true.

Zooplankton and benthic invertebrates appear to be relatively more sensitive to sodium chloride concentrations than fish. As well, within a given taxonomic category (e.g., benthic invertebrates or fish), there is significant inter-species variation in salinity tolerances.

Potassium chloride tends to be the most toxic salt to fish and aquatic invertebrates. Magnesium chloride is next in toxicity, followed by calcium chloride and then sodium chloride. Fish fry may be more tolerant of elevated concentrations of calcium compared to sodium chloride.

Limited studies have been conducted of the toxicity of road salts and de-icing salts to aquatic organisms. In general, toxicity is within the same general range of that observed for sodium and calcium chlorides. Road salts, by increasing the mobilization of metals, may enhance the toxicity and adverse environmental impacts from road runoff. Nutrients and organic contaminants may also be carried with this runoff, especially from heavily trafficked highways. This can also contribute to stress on aquatic organisms.

Top

3.1 Acute Toxicity

Data comparing the toxicity of salt to aquatic organisms were compiled by Evans and Frick (2001). Table 1 shows the measured acute values for various freshwater species exposed to sodium chloride during 96-hour acute toxicity tests. Some of the acute data represent 3-day (72-hour) exposures that were converted into 4-day estimates using a conversion factor as described in Evans and Frick (2001). In total there are 28 observations including fish (13), cladocerans (7), and other invertebrates (8). Invertebrates are more sensitive to chloride (i.e. lower 96-h LC50s) than are fish. Certain fish species (e.g., American eel) show high chloride tolerance, with corresponding high LC50 values. The 96-h LC50s range between 1204 to 13,085 mg chloride/L, with a geometric mean of 4033 mg chloride/L. Sublethal effects (immobilization response) in Tubifex tubifex were observed at the lowest chloride concentration of 474 mg/L. In this particular test, the immobilization response is equivalent to a lethal response, since death was confirmed following transfer of immobile worms back into control tube well water (Khangarot 1995).

3.2 Chronic Toxicity

The results of chronic toxicity tests conducted on nine freshwater species indicate that chloride can adversely affect aquatic organisms at concentrations ranging from 735 to 4681 mg/L (Table 2). Logistic modeling of chronic toxicity data (Figure 1) indicates that the 5th percentile of the sensitivity distribution for aquatic life occurs at around 213 mg/L Cl-. However, limitations in the available input data restrict the application of this relationship for deriving water quality guidelines. For this reason, Evans and Frick (2001) used the available toxicological data and published acute:chronic ratios to estimate chronic toxicity thresholds for various species of aquatic organisms. The reconstructed species sensitivity distribution was developed by first categorizing the exposure period used in the original studies into < 1 day, 1 day, 4 days, and 1 week. The

extent to which these represent chronic versus acute exposure periods depends on the life history of the specific test organism used. Evans and Frick (2001) further standardized the data for exposure period, to reflect longer-term (> 1 week) chronic exposure periods. Based on an acute:chronic ratio of 7.0, the 96-h acute toxicity data were extrapolated to a predicted chronic toxicity threshold, as shown in Figure 2. The predicted community response to chloride is shown in Table 3, which presents the cumulative percentage of species affected by chronic exposures to chloride.

· Top

3.3 Review of Water Quality Criteria for Chloride in Other Jurisdictions

Four jurisdictions have developed water quality criteria for chloride; these criteria are shown in Table 4 and are described below.

3.3.1 State of Kentucky

Birge et al. (1985) recommended that, in order to protect aquatic life and its uses, for any consecutive 3-day period:

1. The chloride concentration should not exceed 600 mg/L;
2. The maximum concentration should not exceed 1,200 mg/L;
3. Chloride concentrations may average between 600-1,200 mg/L for up to 48 hours.

The 1,200 mg/L value was determined from an investigation of benthic community structure and fish survivorship at 7 sites downstream of a salt seepage. Survivorship and diversity was lower at the 1,000 mg/L than the 100 mg/L site and further reduced at the 3,160 mg/L site. In the laboratory, toxicity studies determined a final acute value of 760 mg/L chloride, and a final chronic value of 333 mg/L chloride.

· Top

3.3.2 United States

Water quality criteria for chloride were developed by USEPA (1988). They concluded that except possibly where a locally important species is very sensitive, freshwater organisms and their uses should not be appreciably affected unacceptably if:

1. The 4-day average concentration of chloride, when associated with sodium, does not exceed 230 mg/L more than once every three years on average;
2. The 1-hour average chloride concentration does not exceed 860 mg/L more than once every three years on average.

The criterion maximum concentration, 860 mg/L, was obtained by dividing the final acute value, 1,720 mg/L by 2. The criterion continuous concentration, 230 mg/L was obtained by dividing the final chronic value by the final acute:chronic ratio (ACR), 7.594. USEPA (1988) noted that these criteria will not be adequately protective when the chloride is associated with potassium, calcium, or magnesium. Further, they also noted that because animals have a narrow range of acute sensitivities to chloride, excursions above this range might affect a substantial number of species.

· Top

3.3.3 Canada — Freshwater

CCME (1999) has developed a number of water quality guidelines for chloride, although none are for the protection of aquatic life. These guidelines include:

1. For Canadian drinking water, chloride concentrations should not exceed 250 mg/L. This rationale is based on taste rather than human health considerations.

2. For irrigation waters, sensitive plants should not be irrigated with waters >100 mg/L while tolerant plants can be irrigated with water up to 700 mg/L. This guideline suggests that some sensitive wetland and aquatic plants would be adversely affected by growing in road salt contaminated waters at chloride concentrations as low as 100 mg/L. Quebec maintains identical guidelines.

3. Livestock can be safely watered with concentrations of total soluble salts of up to 1,000 mg/L. However, at concentrations of 1,000-3,000 mg/L livestock health may become impaired. This guideline suggests that terrestrial animals obtaining their drinking water from streams, marshes, and ponds would have their health impaired at these chloride levels. Some animals may be even more sensitive to chloride (i.e., at concentrations < 1,000 mg/L). There is no specified standard in Quebec.

4. In Quebec, aquatic life suffer acute toxicity at minimum chloride concentrations of 860 mg/L. Chronic toxicity occurs at chloride concentrations of 230 mg/L and any increases must not exceed 10 mg/L.

3.3.4 Canada — Marine and Estuarine Life

CCME (1999) has developed an interim water quality guideline for salinity (expressed as parts per thousand) for the protection of marine and estuarine life. Specifically:

> "Human activities should not cause the salinity (expressed as parts per thousand) of marine and estuarine waters to fluctuate by more than 10% of the natural salinity expected at that time and depth."

Top

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· Top

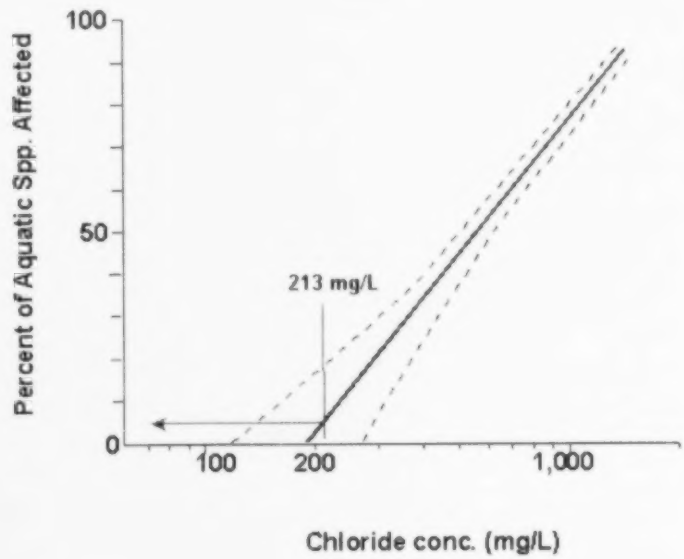

Figure 1. Aquatic life chronic species sensitivity distribution for chloride ion based on laboratory toxicity test data (adapted from Evans and Frick, 2000). The upper and lower 95% confidence interval are also shown. Source: Bright and Addison (2002).

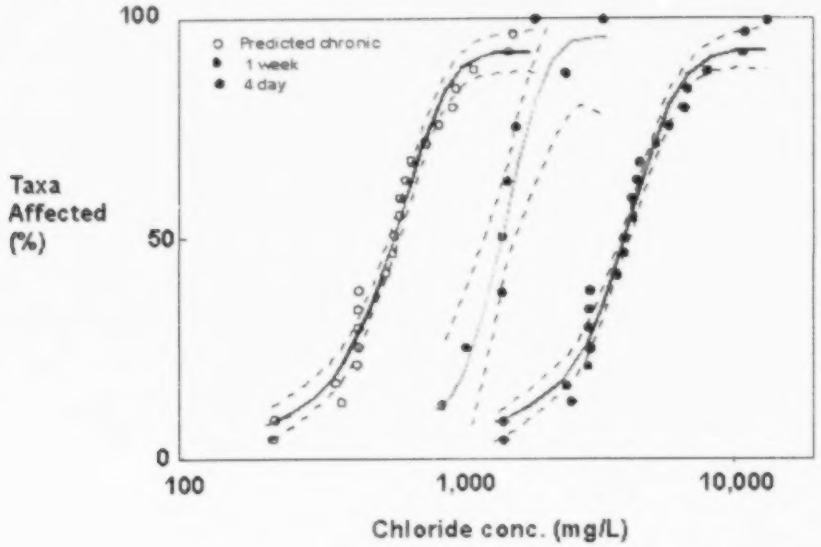

Figure 2: Predicted chronic and actual (4 day and one week) toxicity levels for aquatic life exposed to NaCl. (upper and lower 95% confidence intervals based on a log-logistic fit are shown). Source: Bright and Addison (2002).

· Top

Table 1. Four-day LC_{50}s of various taxa exposed to sodium chloride (adapted from Table 7-5 in Evans and Frick 2001 and Table B.6 in Bright and Addison 2002).

Species	Common Name	96 h LC_{50} (mg Cl/L)	References
Tubifex tubifex	Tubificid worm	1 204	Khangarot, 1995
Ceriodaphnia dubia	Cladoceran	1 400	Cowgill and Milazzo, 1990
Daphnia pulex	Cladoceran	1 470	Birge et al., 1985
Ceriodaphnia dubia	Cladoceran	1 596	WI SLOH, 1995
Daphnia magna	Cladoceran	1 853	Anderson, 1948
Daphnia magna	Cladoceran	2 390	Arambasic et al., 1995
Physa gyrina	Snail	2 480	Birge et al., 1985
Lirceus fontinalis	Isopod	2 970	Birge et al., 1985
Cirrhinius mrigalo	Indian carp fry	3 021	Gosh and Pal, 1969
Labeo rohoto	Indian carp fry	3 021	Gosh and Pal, 1969
Catla catla	Indian carp fry	3 021	Gosh and Pal, 1969
Daphnia magna	Cladoceran	3 658	Cowgill and Milazzo, 1990
Cricotopus trifascia	Chironomid	3 795	Hamilton et al., 1975
Chironomus attenatus	Chironomid	4 026	Thorton and Sauer, 1972
Hydroptila angusta	Caddisfly	4 039	Hamilton et al., 1975
Daphnia magna	Cladoceran	4 071	WI SLOH, 1995
Limnephilus stigma	Caddisfly	4 255	Sutcliffe, 1961
Anaobolia nervosa	Caddisfly	4 255	Sutcliffe, 1961
Carassius auratus	Goldfish	4 453	Adelman et al., 1976
Pimephales promelas	Fathead minnow	4 600	WI SLOH, 1995

Pimephales promelas	Fathead minnow	4 640	Adelman et al., 1976
Lepomis macrochirus	Bluegill	5 840	Birge et al., 1985
Culex sp.	Mosquito	6 222	Dowden and Bennett, 1965
Pimephales promelas	Fathead minnow	6 570	Birge et al., 1985
Lepomis macrochirus	Bluegill	7 864	Trama, 1954
Gambusia affinis	Mosquito fish	10 616	Wallen et al., 1957
Anguilla rostrata	American eel	10 900	Hinton and Eversole, 1978
Anguilla rostrata	American eel	13 085	Hinton and Eversole, 1978

· Top

Table 2. Results of chronic toxicity tests (> 7 day duration) conducted on freshwater organisms exposed to sodium chloride (adapted from Table 7-6 in Evans and Frick 2001 and Table B.6 in Bright and Addison 2002).

Species	Common Name	LC_{50}/EC_{50} (mg Cl/L)	Measured Endpoint	References
Ceriodaphnia dubia	Cladoceran	735	brood size	Degreave et al., 1985
Pimephales promelas	Fathead minnow	874	survival	Beak 1999
Ceriodaphnia dubia	Cladoceran	1 068	brood size	Cowgill and Milazzo, 1990
Oncorhynchus mykiss	Rainbow trout	1 456	survival	Beak 1999
Nitschia linearis	Diatom	1 475	cell numbers	Gonzales-Moreno *et al.*, 1997
Xenopus leavis	Frog	1 524	survival	Beak, 1999
Oncorhynchus mykiss	Rainbow trout	1 595	survival	Beak, 1999
Daphnia magna	Cladoceran	2 451	brood size	Cowgill and Milazzo, 1990
Pimephales promelas	Larvae	3 029	growth	Beak, 1999
Lemna minor	Duckweed	3 150	population	Buckley *et al.* 1996
Myriophyllum spicatum	Eurasian Watermilfoil	4 291	population	Stanley, 1974
Myriophyllum spicatum	Eurasian Watermilfoil	4 681	growth	Stanley, 1974

· Top

Table 3. Predicted cumulative percentage of species affected by chronic exposures to chloride (from Evans and Frick 2001).

Cumulative % of species affected	Mean chloride concentration (mg/L)	Lower confidence limit (mg/L)	Upper confidence limit (mg/L)
5	213	136	290
10	238	162	314
25	329	260	397

50	563	505	622
75	964	882	1045
90	1341	1254	1428

Table 4. Existing water quality criteria for chloride, as reported by Evans and Frick (2001).

	State of Kentucky: Birge et al (1985)	USA: USEPA (1988)	Canada: CCME (1999)	Quebec: CCME (1999)
Freshwater Aquatic Life: Average chloride concentration (mg/L)	600	230		230
Maximum chloride concentration (mg/L)	1,200	860		860
Drinking water (mg/L)			250	250
Irrigation water (mg/L)			100 - 700	100 - 700
Livestock (mg/L)			1000	1000
Wildlife (mg/L)			1000	
Marine water (ppt)			+/-10	

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